SOME ADVANCES IN TECHNIQUES FOR FREE-FLIGHT TESTING

IN HYPERSONIC WIND TUNNELS

by

Lionel L. Levy, Jr., and John B. McDevitt

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California

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INTRODUCTION

In recent years there has been a growing emphasis on the development of free-flight testing techniques for hypersonic wind tunnels. The motivation for this work has been the desire to obtain aerodynamic data free of support interference and to promote flows around test models more nearly representative of the real flight case. Several years ago the Naval Ordnance Laboratory successfully developed the free-flight technique for a shock tunnel (ref. 1). The models were supported by fine wires or threads which blew away upon initiation of flow. Subsequent motion of the model was recorded photographically and the aerodynamic characteristics were deduced from the motion history. More recently Bain Dayman developed a somewhat different technique for the Jet Propulsion Laboratory's hypersonic wind tunnel (ref. 2). In this case the models are launched upstream from a pneumatic-type launcher and the motion of the model in both the upstream and downstream traverse of the test section is recorded photographically. Again, the aerodynamic data are deduced from the motion history. Currently, these free-flight techniques are being exploited and extended at Ames Research Center to permit (1) measurement of local pressure and heat transfer, and (2) the measurement of aerodynamic characteristics of models under conditions of steady-state ablation. It is the purpose of this note to report briefly on these latter developments.

NOTATION

h	enthalpy, Btu/lb
M_∞	free-stream Mach number
p_∞	free-stream pressure, psi
$p_{afterbody}$	afterbody pressure on model, psi
p_{base}	base pressure on model, psi
p_o	reservoir pressure, psi
$\dot{q}$	heating rate on model, Btu/ft^2-sec
T_o	reservoir temperature, ^oR

Conversion to the International System of Units

$$1 \text{ psi} = 6895 \text{ Newtons/(meter)}^2$$

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To develop satisfactory telemetry for measuring heat-transfer, tests were first made on a sting-mounted model so that direct-measured and telemetered results could be compared. Two thermocouples were mounted in the stagnation region and two on opposite sides of a blunted cylinder (fig. 2). One of each pair was connected to an FM telemeter and the other to a direct readout oscillograph. The development phase was concluded when good agreement was obtained between the telemetry data and the direct readout data. Spheres and slender cones were then equipped with FM telemetry systems to measure pressure and temperature and were flown in the shock tunnel. Typical values of pressure and heating rate measured in free flight are indicated in figure 2. Attention is called to the wide range of heating rates, that is, heating rates from 126 down to 0.93 Btu/ft^2-sec. Total error in either pressure or heating-rate measurements is believed to be less than 5 percent. Since the intrinsic accuracy of the systems, particularly the pressure telemetry system, is much better than this, improved test techniques should lead to results with errors significantly less than 5 percent.

In the development of the FM telemetry for the shock tunnel it was found that the plasma sheath around the forward section of the blunt models (fig. 3) could couple electrically with the telemeter to produce substantial frequency shifts and thus render the data useless. As reported in detail in reference 3, it was found for the cases studied that proper shielding at the nose of a model could eliminate the troublesome interference. However, this is a problem that requires further study. Conceivably, it could preclude the use of existing telemetry systems in higher enthalpy flows where the plasma sheath would have greater conductivity and would be more extensive.

MEASUREMENT OF AERODYNAMIC CHARACTERISTICS OF ABLATING MODELS

There is an obvious need for data on the effects of ablation on the aerodynamic and thermodynamic characteristics of entry bodies. Since the effect of the ablation gases is likely to influence the flow over the afterbody, it is highly desirable to conduct the required tests without sting or model support. The advantages of a free-flight technique are obvious. A study with the over-all objective of adapting free-flight techniques for use in arc-jet wind tunnels was recently initiated at Ames by Lionel Levy. The preliminary objective was to determine whether or not models could be successfully free flown in the arc-jet wind tunnel for sufficient time to obtain dynamic-stability data. Presuming this could be done, subsequent objectives were to develop the techniques for measuring the static and dynamic aerodynamic characteristics and ultimately to develop techniques for measuring pressure and heat transfer. The preliminary phase of this study has just been completed and is the subject of the remainder of this note.

The arc jet in which these studies were made is shown schematically in figure 4. A vertical arc jet was used so that the model weight could be balanced by the drag force and thus permit maximum viewing time through the test section windows. The test gas is heated by a d.c. arc between water-cooled ring electrodes. The arc is spun at high speeds by the magnetic field produced by coils surrounding the arc chamber. (A more detailed description of a similar arc jet is given in reference 4.) For the present studies, air was introduced to the arc chamber at a pressure of 1 to 1-1/2 atmospheres and was heated to enthalpy levels of 3,000 Btu/lb. It was then expanded through the 15° half-angle conical nozzle to produce a Mach number of 6 (speed of about 11,000 ft/sec) in the test chamber. The conical nozzle provides a free-stream dynamic pressure gradient in the vertical direction which is favorable for matching the model weight and drag.

To insure steady-state ablation for the full interval of free flight, it is necessary to hold the model in the stream until steady-state ablation is obtained and then release it for free flight. Several schemes for accomplishing this were investigated; the one finally selected and used for the tests reported here is shown in figure 4. For the first few seconds of a test, a monofilament fishing line attached to the base of the model holds the model firmly against the end of a 1/4-inch o.d. tube. When steady-state ablation is established, the tube is retracted upward. This exposes the monofilament line to the wake which burns it off leaving the model in free flight. Care must be exercised in adjusting the settling chamber pressure so that the model weight and drag are balanced and the model remains opposite the viewing window during the period of free flight.

Motions of the model are recorded photographically by two movie cameras placed to observe the motion in two orthogonal planes. A photograph of the facility with the cameras in place is shown in figure 5 and a representative frame from one of the early film records is shown in figure 6. Since the picture is an enlargement from a 16 mm movie frame, it is fuzzy. Nevertheless the model with a small section of the monofilament line still attached can be seen through the window.

Early in this study some difficulty was experienced in achieving successful initiation of free flight and in setting the proper reservoir pressure to keep the model within the test section. However, after gaining experience and developing the model release technique previously described, successful flights of both ablating and nonablating models were obtained in about two out of three attempts. Some representative flight statistics are as follows:

REFERENCES

1. Gates, D. F., and Bixler, D. M.: The Measurement of Aerodynamic Forces and Moments in the NOL 4-In. Hypersonic Shock Tunnel No. 3. NOLTR 61-100, 1961.

2. Dayman, Bain, Jr.: Free-Flight Hypersonic Viscous Effects on Slender Cones. AIAA Paper 64-46.

3. McDevitt, John B., Harrison, Dean R., and Lockman, William K.: Measurement of Pressures and Heat Transfer by FM Telemetry From Free-Flying Models in Hypersonic Tunnel Streams. Paper to be presented at the First International Congress on Instrumentation in Aerospace Simulation Facilities, Paris, France, Sept. 28-29, 1964.

4. Gowen, Forrest E., and Hopkins, Vaughn D.: A Wind Tunnel Using Arc-Heated Air for Mach Numbers from 10 to 20. Paper presented at Second National Symposium on Hypervelocity Techniques, Denver, Colorado, March 19 and 20, 1962.

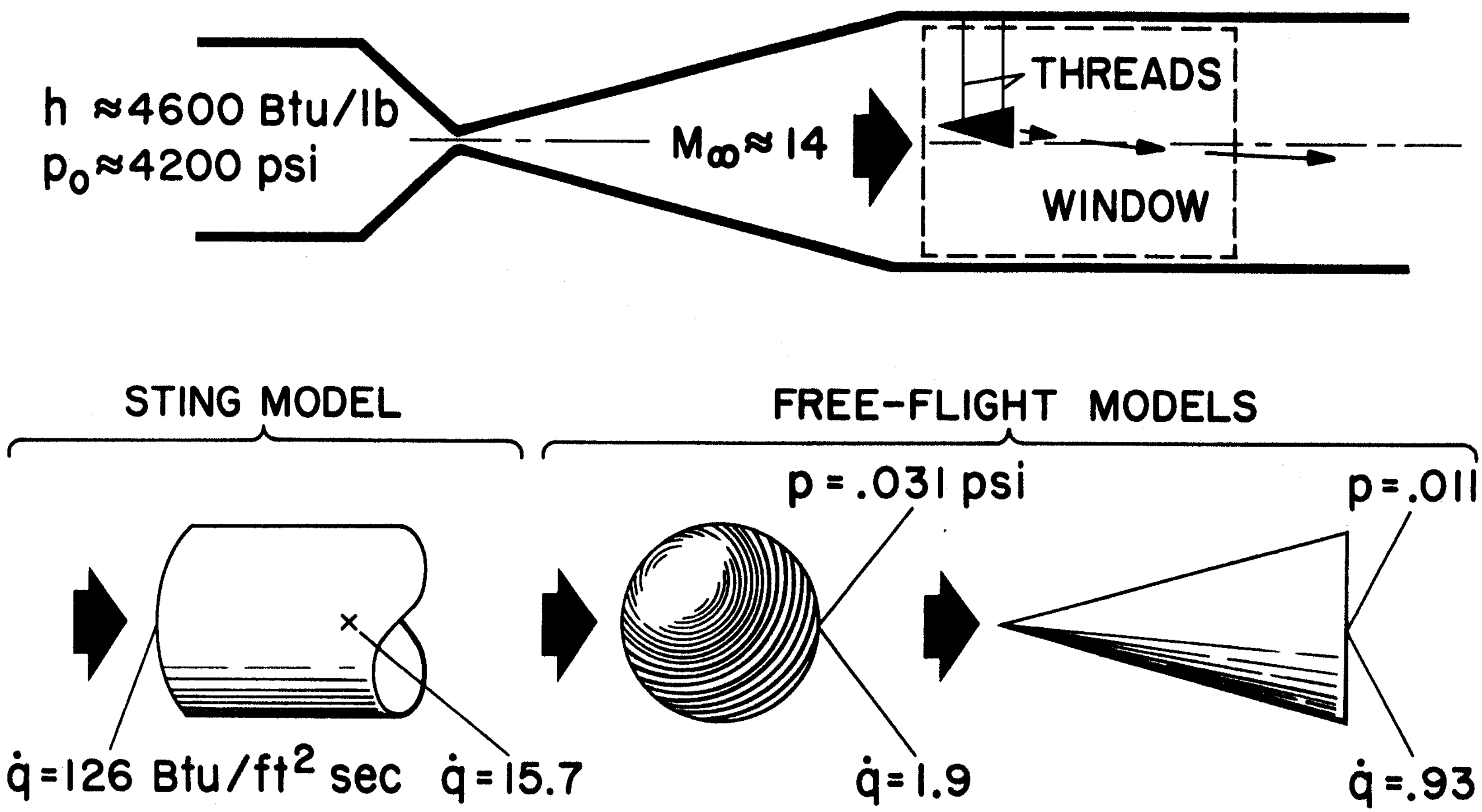

Figure 2.- Pressure and heat-transfer measurements using FM telemetry in the 1-foot shock tunnel.

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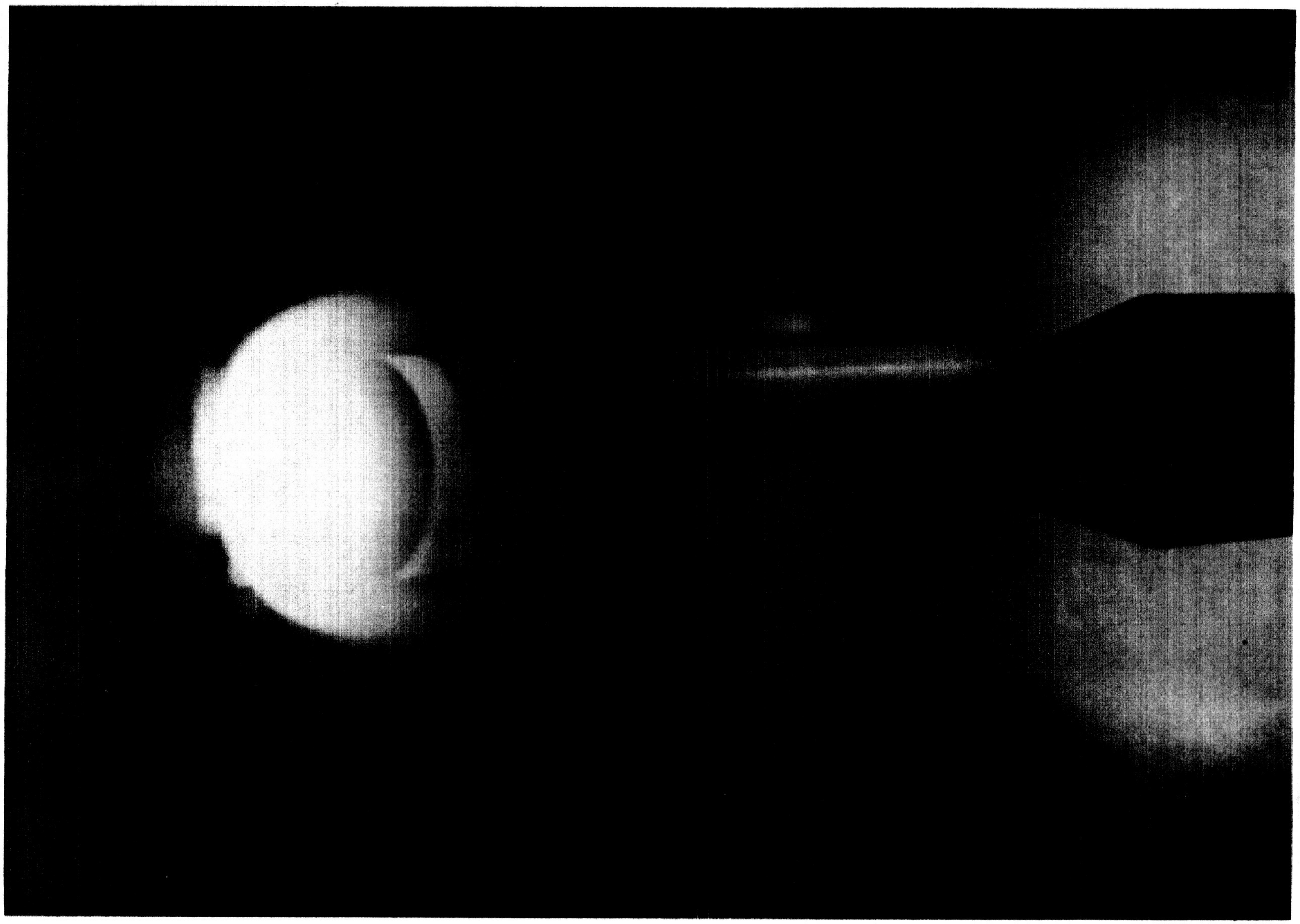

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Figure 3.- Bow-shock illuminated model in 1-foot shock tunnel.

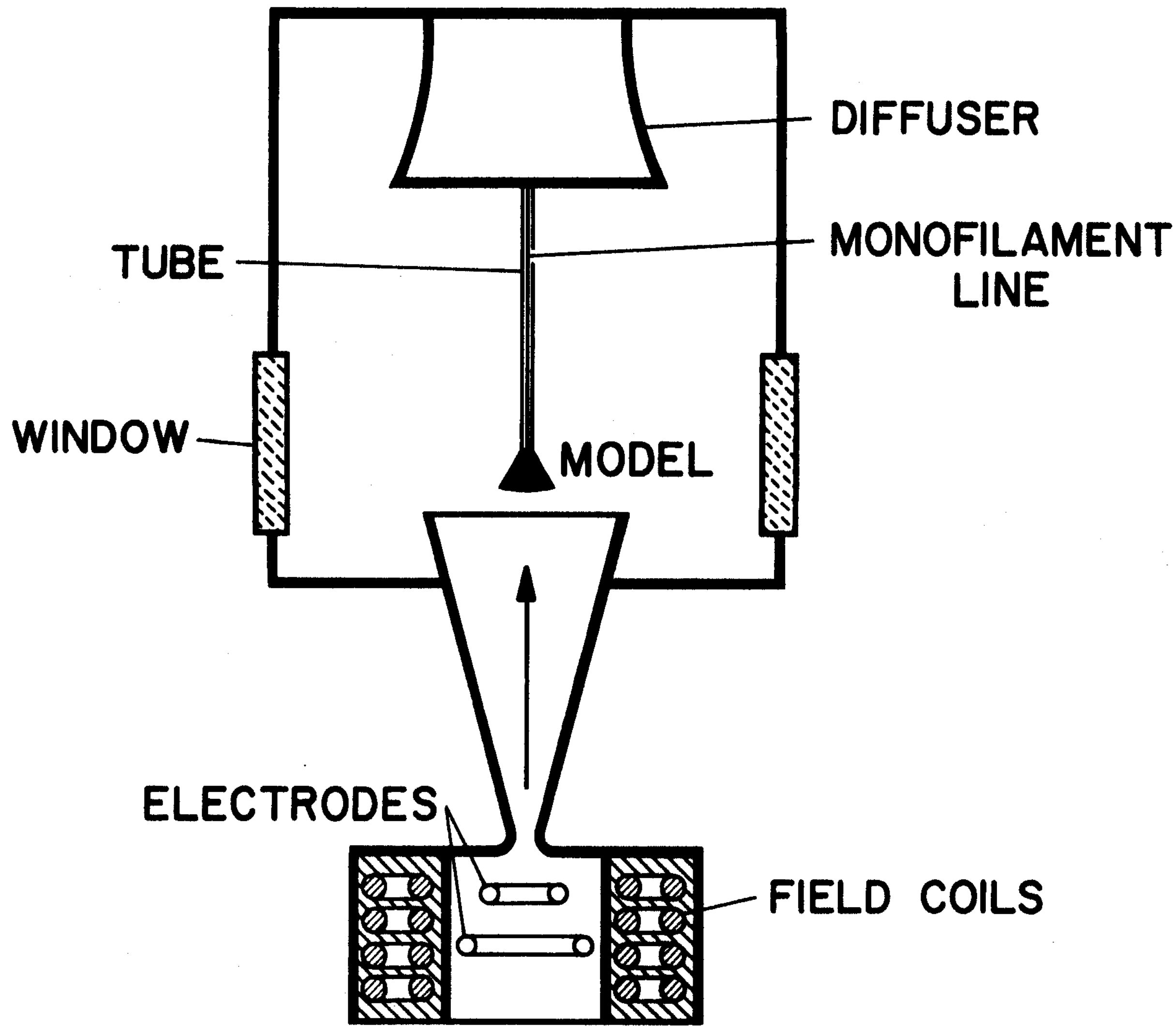

Figure 4.- Schematic arrangement of Ames arc-heated tunnel.

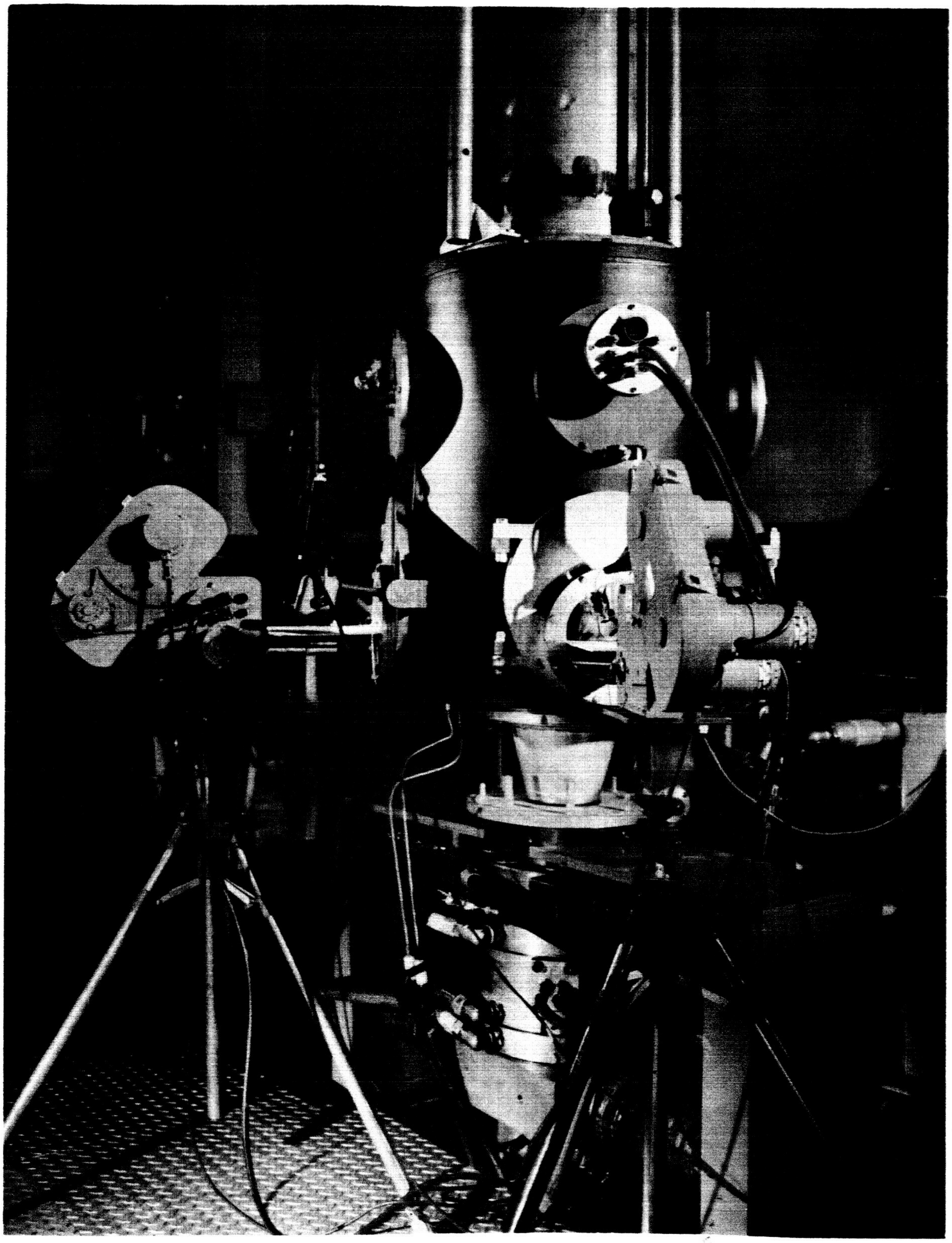

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Figure 5.- Equipment for free-flight ablation tests.

Model	Angle of Attack, deg release	max.	Time, sec	Equiv. Flt. Dist., mi.	Cycles
Nonablating	0	6	9	18	27
"	6	14	2	4	6
Ablating	0	3	8	16	32
"	6	14	1	2	4
Nonablating	0	6	15	30	45

All of the models were similar to the one shown on figure 6; however, the last model was shortened by removing the last half of the conical afterbody.

It should be emphasized that these tests are preliminary and were made primarily to determine whether or not a model could be flown in an arc jet for sufficient time to obtain dynamic stability data. Flight times which provided a minimum of four complete cycles of oscillation were considered to be of sufficient duration to obtain reliable dynamic data. Also, four cycles are more than sufficient to obtain static force and moment data. The results in the above table indicate that the preliminary objective was attained. No attempt has yet been made to analyze the motion histories of the models to obtain aerodynamic data. However, since the results were encouraging, we intend to refine the technique so that useful static and dynamic data can be obtained. Some of the items to be specifically investigated in the near future are:

(1) Contouring of the nozzle to provide more uniform flow in the test chamber and yet maintain the minimum vertical gradient of dynamic pressure required to stabilize model motions in the vertical direction.

(2) Improving photographic techniques so that motion history can be readily and accurately obtained from motion pictures.

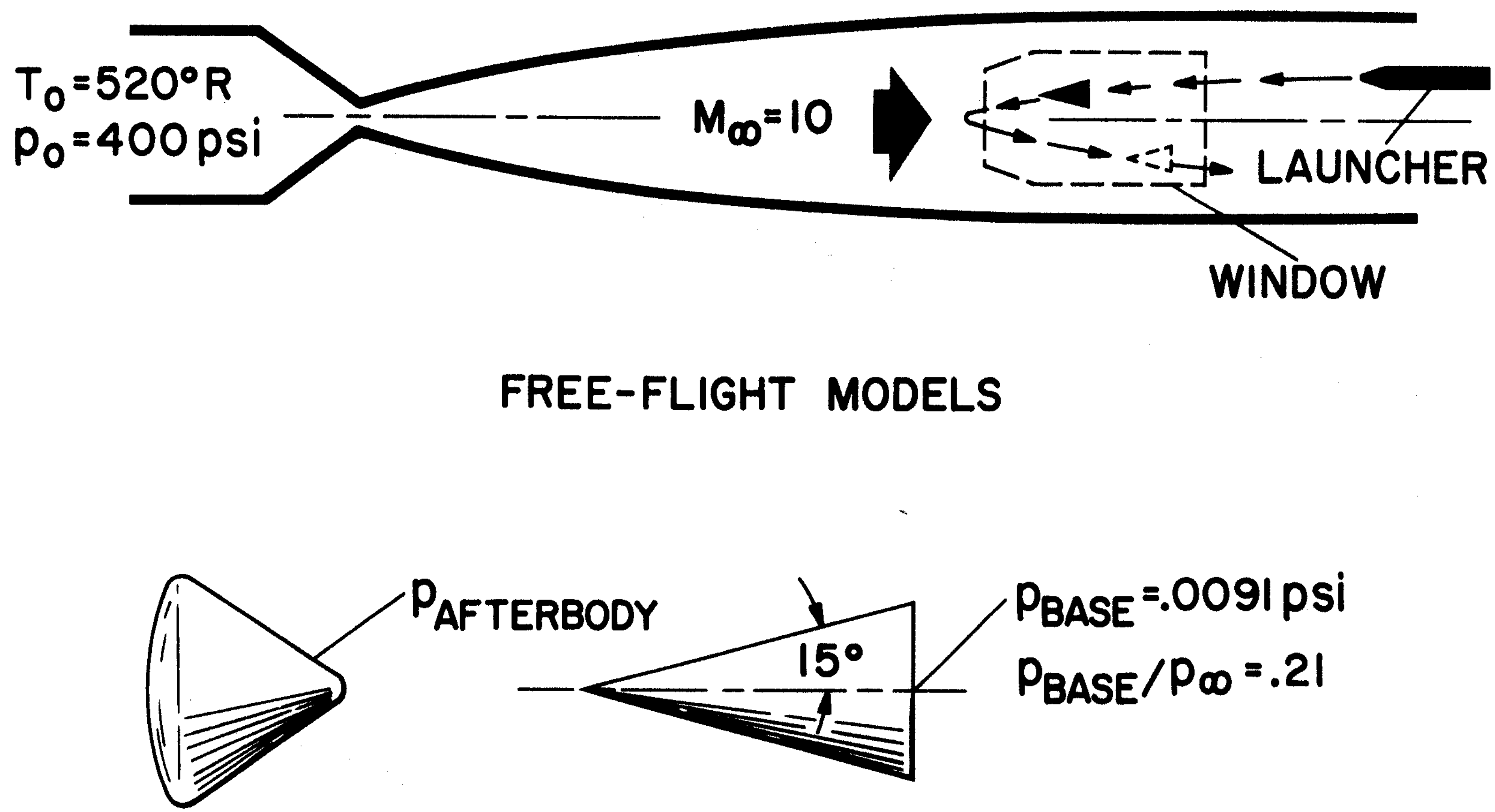

Figure 1.- Pressure measurements using FM telemetry in the 14-inch helium tunnel.

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1 Btu/lb = 2325 joules/kg

1 Btu/ft^2-sec = 11,360 joules/$(meter)^2$-sec

MEASUREMENT OF PRESSURE AND HEAT TRANSFER

The techniques for measuring pressure and heat transfer have been developed in the Ames 14-Inch Helium Tunnel and the 1-Foot Shock Tunnel. The success of these techniques rests on the development of a small reliable FM telemeter and compatible pressure and temperature sensors. Since this development is being reported fully by McDevitt in reference 3, details will not be repeated here. Rather, an attempt will be made to summarize the present state of development and to highlight one of the problems associated with telemetry in high-enthalpy facilities.

The basic FM telemetry and pressure sensing system was developed in the Ames 14-Inch Helium Tunnel shown schematically in figure 1. Although the tunnel is capable of producing Mach numbers of 10, 17, and 21, only the Mach number 10 nozzle was used for the investigation reported here. Models are launched at relatively low speed so that they fly upstream past the test section window, stop just upstream of the window, and then fly back past the window again. The gross force and moment characteristics can be determined from the motion history which is recorded photographically. The local pressure data are obtained from a pressure sensor and an active FM telemeter within the model. The sensor-telemeter system now in use is essentially that described in the paper by Hruby and McDevitt that was presented at the last STA meeting. The only significant difference is a change in the telemetry circuit as described in reference 3. Perhaps most important is the fact that the system is being successfully employed to measure afterbody or base pressures on both blunt and slender entry bodies where the absolute pressures are as low as 0.009 psi. Errors in these measurements are believed to be less than 5 percent.

The adaptation of the techniques just described to permit measurement of pressures and heat transfer in higher enthalpy flows has been the immediate goal of the most recent studies at Ames. These studies have been limited for the present to the 1-Foot Shock Tunnel shown schematically in figure 2. The shock-compressed air in the reservoir section of this tunnel is nominally at an enthalpy of 4600 Btu/lb and a pressure of 4200 psi. Expanding this gas through the 20° nozzle produces Mach number 14 flow in the test section for a useful time of about 20 milliseconds. For most tests, the models have been simply supported by fine threads which are burned off in the first few milliseconds of flow. Although some gross force data have been obtained from model motion histories, greatest effort has been placed upon measurement of local pressure and heat transfer.

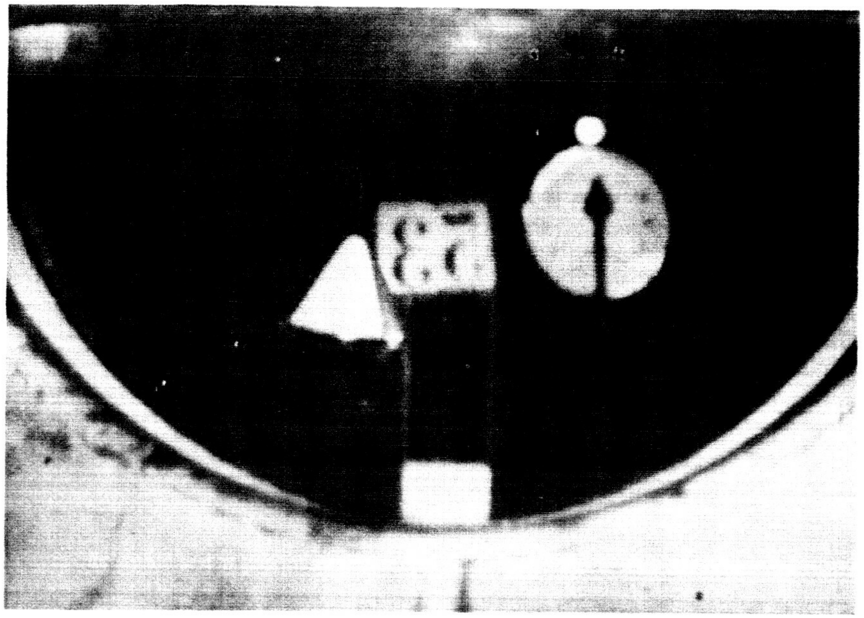

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Figure 6.- Frame from motion-picture record.

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